

AD-A051 400

NAVY ELECTRONICS LAB SAN DIEGO CALIF
A DOPPLER MEASUREMENT EXPERIMENT USING AXIS-CROSSING INTERVALS.(U)
OCT 65 L P MULCAHY
NEL-TM-867

F/G 17/1

UNCLASSIFIED

NL

| OF |
AD
A051 400



END
DATE
FILMED

4-78

DDC

AD A051400

Most Project - 3

SC

U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA

A BUREAU OF SHIPS LABORATORY

This is a working paper giving tentative information about some work in progress at NEL.

If cited in the literature the information is to be identified as tentative and unpublished.

867

Good

DDC
RECEIVED
MAR 16 1978
F

NEL/Technical Memorandum 867

9
TECHNICAL MEMORANDUM
NEL
TM-867

6
A DOPPLER MEASUREMENT EXPERIMENT USING AXIS-CROSSING INTERVALS

11
28 October 1965

12
32p.

10
L. P. Mulcahy (Code 3180)

SF 001 02 05 (6072)
NEL E11161

867

AD No. _____
DDC FILE COPY

16 F00102

17 SF0010205

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

253 550

YB

FOREWORD

This memorandum describes the results of an experiment using 3D, an axis crossing interval measurement device. This memorandum has been prepared since it may be of interest to a limited number of people at NEL and possibly to a few people or activities outside NEL. It should not be construed as a formal report since its function is to present for information a small portion of the work being done in the area of sonar signal measurements and analysis. ~~Limited distribution outside the Laboratory is contemplated.~~ +?

The author wishes to express appreciation to H. T. Magnussen, J. A. Reese, and C. E. Pfefferkorn, who, as student trainees, contributed to the completion of the experiment.

ACCESSION FOR	
NTIS	State Section <input checked="" type="checkbox"/>
DOC	Dist Section <input type="checkbox"/>
UNANNOUNCED	Per ltr <input type="checkbox"/>
DISTRIBUTION	on file
BY	
DISTRIBUTION/AVAILABILITY CODES	
SPECIAL	
A	

CONTENTS

INTRODUCTION ... page 1

Background ... 1

Objectives of the Experiment ... 1

Description of 3D ... 1

Test Instrumentation ... 3

Experimental Method ... 4

RESULTS OF THE EXPERIMENT ... 5

Measurement Artifacts ... 5

On the Use of Reverberation as a Reference ... 8

Doppler Measurements ... 9

CONCLUSIONS ... 13

RECOMMENDATIONS ... 14

ILLUSTRATIONS

- 1 Simplified block diagram of 3D ... page 15
- 2(a) 3D experimental setup: block diagram
- 2(b) Reverberation simulator ... 16
- 3 Timing diagram for 3D experimental setup ... 17
- 4 Typical block of data illustrating measurement artifacts ... 18
- 5 Effect of the pulse generator circuit threshold on axis crossing detector performance ... 19
- 6 Effect of high frequency noise on axis detector performance ... 20
- 7 Variability of 3D measurements as a function of reverberation bandwidth ... 21
- 8 Variability of 3D measurements as a function of N ... 22
- 9 Standard deviation of 3D measurements as a function of the rms signal to rms reverberation ratio: 100 millisecond reverberation ... 23
- 10 Deviation of the computed (experimental) means from the true means as a function of rms signal to rms reverberation ratio: 100 millisecond reverberation ... 24
- 11 Doppler indicator performance as a function of echo doppler and rms signal to rms reverberation ratio: 100 millisecond reverberation ... 25
- 12 Standard deviation of 3D measurements as a function of rms signal to rms reverberation ratio: 30 millisecond reverberation ... 26
- 13 Deviation of the computed (experimental) means from the true means as a function of the rms signal to rms reverberation ratio: 30 millisecond reverberation ... 27
- 14 Doppler indicator performance as a function of echo doppler and rms signal to rms reverberation ratio: 30 millisecond reverberation ... 28

TABLES

- 1 Illustration of the normalization procedure used for Figure 7 ... page 10

INTRODUCTION

BACKGROUND

The Digital Doppler Discriminator, hereafter called 3D, is a device which was designed and constructed under Contract NOnr 3308(00) by Waddell Dynamics, Inc. of San Diego, California. It was designed as a visual echo doppler indicator for use with active sonar systems. One of the two experimental models constructed under this Contract was sent to NEL for laboratory tests. This memorandum describes the experiment performed with 3D, under this contract.

OBJECTIVES OF THE EXPERIMENT

The experiment had two objectives. The first was to determine the capability of 3D as a doppler measuring device. The second was to investigate the statistical behavior of doppler measurements for various mixtures of sine wave signals and simulated reverberation.

DESCRIPTION OF 3D

Functional Description

3D is essentially a digital time-interval measuring device. It measures the difference between two successive time intervals, one for reverberation and one for the target echo, and displays that difference on a bank of colored lights.

In a sonar application, 3D would be connected to the audio channel. The following sequence of operations applies to each measurement (see Figure 1 for a simplified block diagram of 3D):

1. The returning sonar signal is amplified, clipped, and converted to pulses at the positive-going axis-crossings. The forward-backward counter and the axis-crossing counter are initially set to zero.

2. A reverberation trigger pulse is received from the sonar. (This trigger signifies the end of the transmission of a sonar signal into the water. This trigger pulse is delayed within 3D in order to postpone start of the reverberation sample interval until after all switching transients within the sonar have died down. The time delay in 3D is controlled by a potentiometer. For the purpose of the experiment, the time delay was set equal to zero.)
3. At the next positive-going axis-crossing of the sonar signal, the gate is opened by the master control, allowing a high frequency clock to accumulate in the forward-backward counter. (Note: The forward-backward counter is counting in the forward direction during the reverberation sample interval.)
4. When a predetermined number (N) of axis-crossings is counted by the axis-crossing counter, the gate is closed. N is entered manually by the operator. The time interval during which the gate is open is called the "sample interval."
5. The forward-backward counter contents are then proportional to the average period of the reverberation during the sample interval. This interval contained N complete cycles of the sonar signal input.
6. The axis-crossing counter is reset to zero.
7. An echo trigger pulse is received from the sonar. This trigger signifies the position of the cursor tip on the PPI display of the sonar stack. The cursor tip is positioned by the stack operator so that it just touches the target echo. (Note: An echo trigger pulse can also be obtained from a special level detector in 3D. The level detector is enabled by a time interval bracketing the sonar cursor tip. This feature was not used in the experiment.)
8. At the next positive-going axis-crossing, the gate is opened by the master control and the high frequency clock pulses are subtracted from the forward-backward counter contents. (Note: The forward-backward counter is counting in the backward direction during the echo sample interval.)
9. When N axis-crossings are counted by the axis-crossing counter, the gate is closed.
10. An "up" doppler echo (corresponding to a closing target) will have a shorter average period than the reverberation. Therefore, the resulting content of the forward-backward counter will be greater than zero. The contents will be zero for a "no" doppler echo and less than zero for a "down" doppler echo.

In the rest of this memorandum the "resulting contents" of the forward-backward counter will be called a "count-difference." This measurement was recorded on punched paper tape for computer analysis.

Physical Description

3D is housed in a standard electronic equipment cabinet of dimensions 16" x 14" x 23". Most of the circuitry is mounted on plug-in, printed circuit cards which were constructed in a breadboard fashion. The visual display consists of a bank of red, yellow, and green lights which indicate "up," "no," or "down" doppler respectively. These lights are arranged in a row above the front panel. On the front panel are controls for the various 3D functions.

As indicated above, one of the operating parameters to be set by the operator is N, the number of axis-crossings over which the gate is open (i.e., duration of the sample interval). Entry is accomplished by inserting the proper diode matrix card. A number of matrix cards was provided with the equipment for this purpose. Another parameter is the clock frequency, which is controlled by a three-position rotary switch located on the front panel.

TEST INSTRUMENTATION

Figure 2(a) is a block diagram of the experimental setup. The switching amplifier is a low-noise, audio amplifier used to select either a reverberation sample input or an echo sample input. For the echo sample input, the sine wave is added to simulated reverberation. The switching amplifier contains controls for setting the sine wave-to-reverberation ratio when the echo sample input is used.

The timing circuitry is used to control the switching amplifier and to initiate the reverberation and echo gates in 3D. When 3D completes a

a measurement, a print command is sent to the paper tape punch control logic. The paper tape punch then enters that measurement on the paper tape. The timing circuitry allows any number of consecutive measurements to be made automatically for a given set of experimental parameters. When the desired number of measurements is recorded, the system is automatically stopped.

Figure 2(b) shows the method used in simulating reverberation. The active band pass filter has characteristics equivalent to those of a simple LCR filter (tuned circuit). Active filters were used in order to obtain the high Q 's required. The filter bandwidths used were 16.8 and 40.1 cps, corresponding to LCR circuit Q 's of 297.6 and 124.7, respectively. The bands were centered at 5Kc. These bandwidths approximate those of reverberation provided by transmitted pulses with durations of 100 and 30 milliseconds, respectively. In this memorandum this reverberation will be called "100 millisecond reverberation" and "30 millisecond reverberation."

Two highly stable sine wave oscillators were designed and built for use in this experiment. The first is a crystal-controlled oscillator with a frequency of 5000.0 cps. The second is a variable-frequency oscillator which can be set to within 0.1 cps in the band from 4800 to 5200 cps. Frequency calibration was performed using a Hewlett-Packard Model 524 counter-timer in the 10-second averaging mode.

EXPERIMENTAL METHOD

Measurements were performed in blocks of one thousand for each set of experimental parameters. The experimental parameters were: N (number of analog signal cycles), reverberation bandwidth, signal-to-noise ratio, and doppler (frequency) shift of the sine wave relative to the center frequency of the reverberation. Each block of one thousand measurements was

processed by an AN/USQ-17 computer. The computer printouts contained a histogram of the measurements as well as the mean and standard deviation for each block.

RESULTS OF THE EXPERIMENT

MEASUREMENT ARTIFACTS

During initial tests of 3D, occasional erroneous measurements were observed. Figure 4 is a histogram of a typical block of one thousand measurements, showing the presence of systematic errors (referred to as artifacts). Random errors were also observed. The possible causes of these errors are discussed in detail below.

Axis-Crossing Threshold Effect; Systematic Errors

Figure 5 is an illustration of a typical analog signal as it affects the pulse generator circuit shown in Figure 1. The pulse generator circuit acts on the output of the clipper-amplifier. If the analog signal input to the clipper-amplifier is low, insufficient clipping will take place as seen at the output. If the pulse generator threshold is high enough so that it misses one cycle of the clipper-amplifier output signal, then the gate is kept open for $N+1$ cycles instead of N (i.e., the sample interval is too long). This is shown in Figure 5 by the positions of the detected axis-crossings for the clipper-amplifier output signal. The time interval error in this case is approximately one period of the analog signal input. If we use the data in Figure 4 as an example, this error is about 200 microseconds. Since a 100 KC clock was used, this would result in an accumulation of about 20 extra counts in the forward-backward counter (counting in the forward direction). If two cycles of the

clipper-amplifier output signal were missed, we would expect an accumulation of about 40 extra counts, and so on.

Effect of High Frequency Noise; Systematic Errors

Another source of systematic errors is relatively high frequency and/or wide-band noise overriding the normal clipper-amplifier output signal. The effect is dependent on low signal-to-noise ratios. This should occur for low amplitude analog signals since the noise is usually low amplitude also. Figure 6 shows the same analog signal as given in Figure 5, except a high frequency constant amplitude noise signal has been added to it. It is assumed that the addition takes place at the input to the clipper-amplifier. When the input to the clipper-amplifier becomes low, so that insufficient clipping takes place at the clipper-amplifier output, the "ripple" caused by the addition of noise predominates. In this case, the sample interval is too short, since two extra analog signal cycles are counted. This is shown in Figure 6 by the positions of the detected axis-crossings for the clipper-amplifier output signal. Thus, the gate is kept open for $N+2$ cycles instead of N . Again referring to the data in Figure 4, this effect would result in a deficiency of around 20, 40, etc. counts in the forward-backward counter, provided the sample interval begins and ends at axis-crossings caused by the analog signal alone. It should be noted that if the sample interval begins and/or ends at axis-crossings caused by noise, it is possible for the count deficiency to be some number distinctly different from an integral multiple of 20.

Conclusion; Systematic Errors

We can apply the above reasoning to the data in Figure 4 to determine which of these effects predominates. Note that a pure sine wave was used

for the reverberation sample input for these data. This means we would expect the measurement errors to occur during the echo sample interval since this would be the only time during which the analog signal input amplitude could be low enough for the threshold effect to take place or for high frequency noise to affect the clipper-amplifier output. Therefore, if some analog signal cycles were missed due to the threshold effect, the count differences would be negative in sign. Only one occurred in this block of data. If high frequency or wide-band noise were present, the count differences would be positive. Eleven occurred in these data, indicating that count difference errors in this case are due primarily to high frequency and/or wide-band noise.

Effect of Electrical Transients; Random Errors

It was observed that both positive and negative count difference errors could result, depending on whether transients enter 3D during the reverberation sample interval or the echo sample interval. In other words, transients induced in the A.C. line connected to 3D caused artifacts to appear. This effect was checked out using a pure sine wave for both the reverberation and echo samples, thereby eliminating the possibility of systematic errors. Electrical transients were induced by switching a solder gun on and off during the sample intervals. The power supply output connected to the pulse generator circuitry was observed to fluctuate whenever the solder gun was used. The same transients were observed when the solder gun was used in another room, eliminating the possibility of air-borne interference. Thus, it was these power supply variations which caused extra pulses to be generated by the pulse generator and erroneous count differences to appear.

ON THE USE OF REVERBERATION AS A REFERENCE

In the preceding discussion, it was stated that the first 3D sample interval contains N cycles of reverberation resulting from an active sonar transmission. The count from this reverberation sample interval is used as a reference with which the count for N cycles of the echo is compared. The resulting count difference is a function of the movement of the echo-producing target relative to the water. The question we wish to examine is: What measurement variations are introduced if we use reverberation for a reference sample? To answer this question, we outline two hypotheses and attempt an experimental verification of them.

The first hypothesis concerns the variability of axis-crossing interval measurements as a function of the bandwidth of the random signal being measured. We expect that narrow-band signals will look very much like pure sine waves on an individual cycle basis. We further expect that as a random signal becomes more narrow-band, these individual cycles will become more uniform. Thus, the axis-crossing intervals should become more uniform also. With regard to 3D measurements for a given sample interval (i.e., given center frequency and N), the wider the reverberation bandwidth, and more variable we expect the measurements to be. The data in Figure 7 are typical results of the experiment. These data show that measurement variability decreases as reverberation bandwidth is decreased.

The second hypothesis is that increasing the sample interval for the reverberation results in a decrease of the variability of the measurements. This decrease would be due to averaging of the reverberation axis-crossing intervals within the sample interval. Typical results are shown in Figure 8. The data for $N = 50$ and $N = 500$ were normalized with

respect to the data for $N = 10$. (Table 1 illustrates the normalization procedure.) Note that as the sample interval is increased from $N = 10$ to $N = 50$, there is a decrease in measurement variability (shown in knots). However, when the sample interval is increased to $N = 500$, the basic shape of the distribution becomes highly skewed. This is probably due to high frequency noise. For Figure 8, reverberation was used as a reference and a pure sine wave as the echo; whereas, in Figure 4, the converse was true. Thus, in this case, noise present during the reverberation sample intervals would result in negative bias for the distribution. (See the previous section on measurement artifacts.) The data in Figure 8 also support our contention that artifacts due to high frequency noise occur only when the reverberation amplitude is quite low or at a minimum. We expect the minimum in the reverberation to be random in time of occurrence relative to the 3D reference sample interval. Thus, for narrow-band reverberation and a short sample interval, we expect few measurements to be affected. As the sample interval is increased, a higher percentage of measurement should be affected. Our simulated 100 millisecond reverberation (actually white noise band-limited to about 17 cps) exhibits "globs" approximately 60 milliseconds long, so that the minima are roughly 60 milliseconds apart. Therefore, nearly all of the 100 millisecond reference sample intervals will have captured a minimum of the analog signal; whereas about one in six 10 millisecond reference sample intervals, and one in fifty 2 millisecond reference sample intervals will have captured a minimum.

DOPPLER MEASUREMENTS

Characteristics of 3D Analog Signal Inputs

This part of the experiment was carried out using a constant frequency sine wave at 5000.0 cps for the reference sample. This was done to insure

Sample Interval	Count Differences				
N = 500	...	-74 to -25	-24 to +25	+26 to +75	+76 to +125
N = 50	...	-7 to -3	-2 to +2	+3 to +7	+8
N = 10	...	-1	0	+1	+2
					...

Table 1. Illustration of the Normalization Procedure Used for Figure 7.

NOTE: In order to compare one histogram with another, it is necessary to adjust the horizontal scales so that all of the class boundaries or subdivisions are equivalent in terms of the variable that is subdivided. That is to say, the class boundaries have to be equivalent from one histogram to another. In this Table we have chosen the class boundaries to be constant in knots doppler, not count differences. For example, for $N = 10$, the class boundaries would be $+0.5, +1.5, \dots$ count differences. These correspond to $+3.65, +10.95, +18.25, \dots$ knots. For $N = 50$, the equivalent class boundaries in count differences are $+2.5, +7.5, +12.5, \dots$. For $N = 500$, the equivalent class boundaries in count differences are $+25, +75, +125, \dots$. (Since the latter boundaries occur at specific count difference values, they were offset by 0.5 in order to put the boundaries midway between two consecutive values. Therefore, the adjusted count difference values are $\dots, -74.5, -24.5, +25.5, +75.5, \dots$)

that any variation in 3D measurement would be due primarily to the variation of the axis-crossing interval statistics of the echo sample. The echo signal consisted of a sine wave of constant frequency additively mixed with simulated reverberation. The sine wave frequency was varied to correspond to various values of doppler shift relative to a 5 Kc center frequency. Doppler shifts of +20, +10, +5, +3, +2, +1, +0.5, 0, -1, and -5 knots were used. The range of signal-to-reverberation ratios depended on the type of reverberation that was used in a particular instance.

Results Using 100 Millisecond Reverberation

Figure 9 shows the standard deviation of 3D measurements over all dopplers as a function of the signal-to-reverberation ratio. Some of the standard deviations are recomputed values which do not include probable artifacts. Measurements that were suspected to be artifacts occurred for signal-to-reverberation ratios of 3/2 and 2 for all dopplers, and for a signal-to-reverberation ratio of 3 for only one doppler. All other measurements appeared to be free of artifacts.

Figure 10 shows the deviation of the experimental means of the 3D measurements from the expected value of the true means over all dopplers as a function of signal-to-reverberation ratio. The expected value of the true mean, for a particular value of doppler, was computed as the average count difference value that would occur if a pure sine wave was used for an echo. The deviation is expressed in terms of cycles-per-second difference in frequency as well as the equivalent in count differences and knots. These data were also corrected for artifacts. The data in Figure 10 indicate a systematic negative bias of about 0.05 cps. This is probably due to slight errors in calibration, since the sine wave generators were set to a given frequency within 0.1 cps using a digital frequency meter.

However, when the deviation in knots is considered, we find that this bias is quite small. The maximum range of the mean deviation over all dopplers also is relatively small, compared with the corresponding standard deviations shown in Figure 9.

Figure 11 shows the proportion of measurements which results in the correct doppler category of "up," "no," and "down" doppler for certain selected doppler categories. An assignment of "up" doppler was made for all count differences greater than +4, "down" doppler for all count differences less than -4, and "no" doppler for count differences ranging from -4 to +4. The "no" doppler class boundary thus corresponds to roughly 0 ± 0.5 knots. These data were left uncorrected for artifacts so as to provide an indication of the true effectiveness of 3D as a doppler indicator. The unsymmetrical behavior of the curves for signal-to-reverberation ratios of 2 and 3/2 is probably due to the effect of high-frequency noise. Since the reverberation is present only during the echo sample interval, high-frequency noise would cause a positive bias to appear in the measurements. A "down" doppler echo would then not always be measured as "down" whereas an "up" doppler echo would nearly always be measured as "up".

Results Using 30 Millisecond Reverberation

Figures 12, 13, and 14 are similar to Figures 9, 10, and 11 in the previous section. Artifacts apparently did not occur for these data, so no adjustments were made in the computations. The primary difference between these data and the data of the preceding section is that more variation in 3D measurements is observed. This is due to the shorter 3D sample interval as well as the wider reverberation bandwidth. The effect of reverberation bandwidth on the variability is shown for comparison in Figure 12 for 5 blocks of data, obtained using 100 millisecond reverberation

with a 10 millisecond sample interval. The "no" doppler class boundaries in Figure 14 are ± 0.5 knots, the same as for Figure 10.

CONCLUSIONS

1. Artifacts appeared to be the main sources of error in 3D measurements. It was determined that these may be due to a threshold effect, high frequency noise, or to power line transients affecting the axis-crossing detector circuitry. These problems indicate that improvements should be made in a number of circuit design areas. Desirable improvements include effective power supply filtering of power line transients, decreased axis-crossing detector thresholds, and better noise figure in the analog signal amplifiers and their inputs.

2. Reverberation is useful as a reference only for long transmitted pulse lengths and long sample intervals (i.e., long averaging times) provided the artifacts are eliminated. Even so, we expect some measurement variability. If reverberation is not used as a reference in 3D, the only alternative is to use a stable sine wave signal taken from the sonar. This signal may be either the transmitted frequency or the transmitted frequency modified according to own ship's velocity and the direction of the audio beam relative to the ship's direction of motion.

3. In this experiment, doppler measurements were carried out using a pure sine wave for an echo. It should be emphasized that the resulting curves represent a "best case." It is hard to predict the doppler measuring performance of 3D with real submarine echoes, since actual echo characteristics may cause the 3D measurements to be much more variable.

4. The position of the sample interval within the echo is an important consideration. 3D is designed to be triggered either by a pulse

corresponding to the cursor tip on the sonar PPI, or by a signal derived from a special level detector in 3D. In either case, it is not possible to be sure that the sample interval is within the echo since 3D does not have a display. A visual indicator (A-scan, for example) that marked the position of the sample interval relative to the sonar signal would aid the operator to evaluate the reliability of the 3D measurement. Even so, we don't know if the echo characteristics are consistent enough to permit measurements over one unbroken time interval, or if a number of smaller intervals within one echo are better suited for measurement.

RECOMMENDATIONS

3D appears to be poorly suited for use as a sonar doppler measuring instrument for the reasons listed in the Conclusions section of this memorandum. However, axis-crossing intervals may be a good source of information about sonar signals if they are properly handled and interpreted. Therefore, it is our recommendation that an investigation be undertaken of the axis-crossing behavior of sonar signals on a cycle-by-cycle basis, to determine the doppler information content of such signals and optimum extraction techniques.

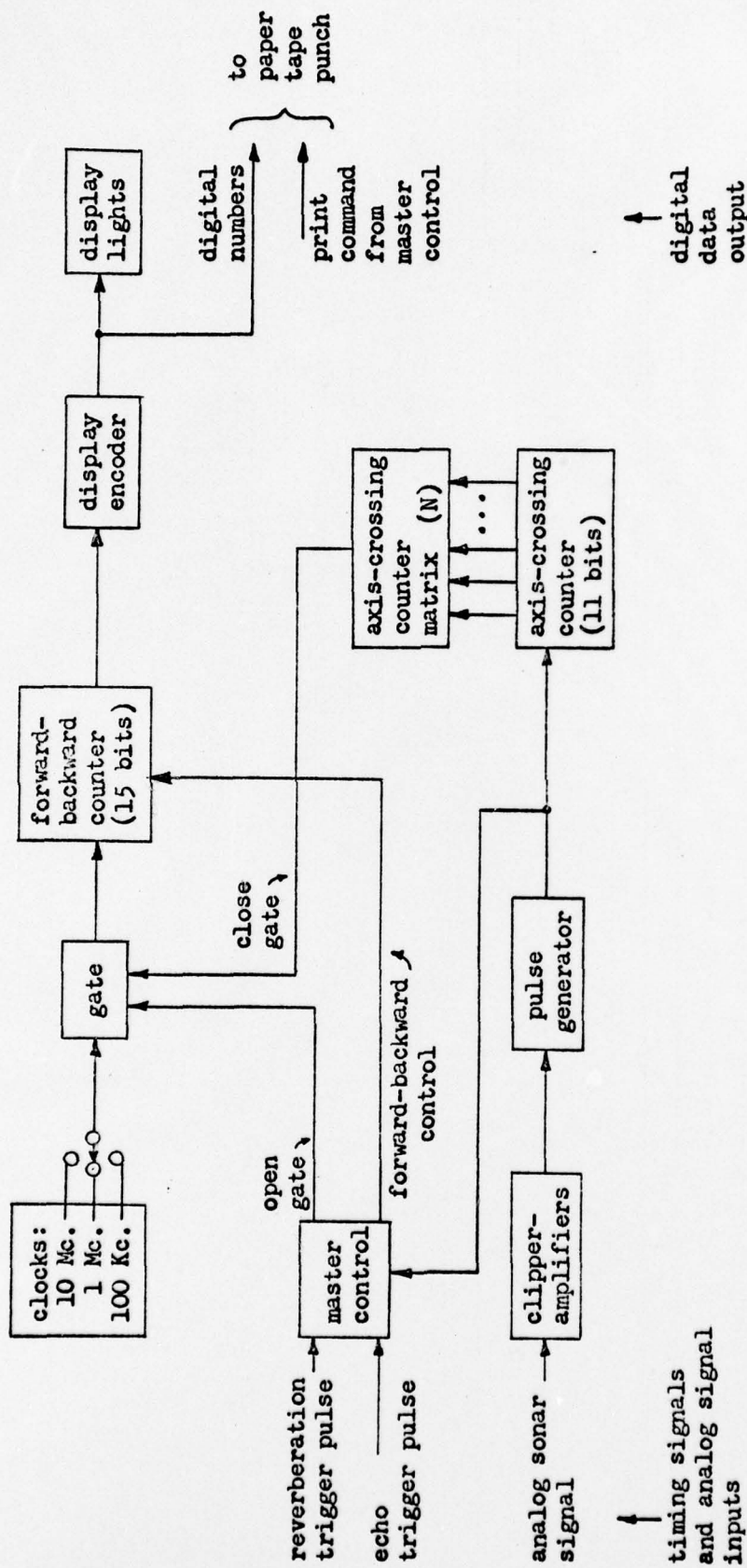
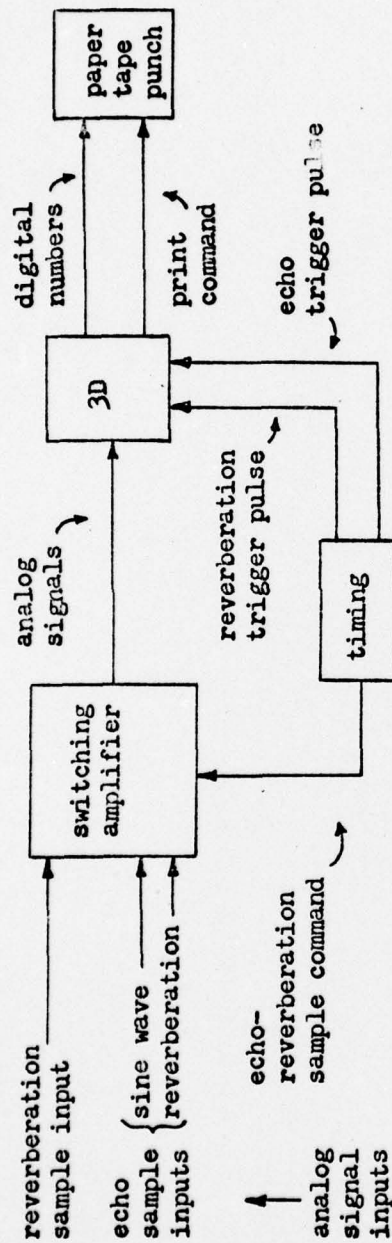


Figure 1. Simplified block diagram of 3D.



(a)



(b)

Figure 2. (a) 3D experimental setup: block diagram

(b) Reverberation simulator

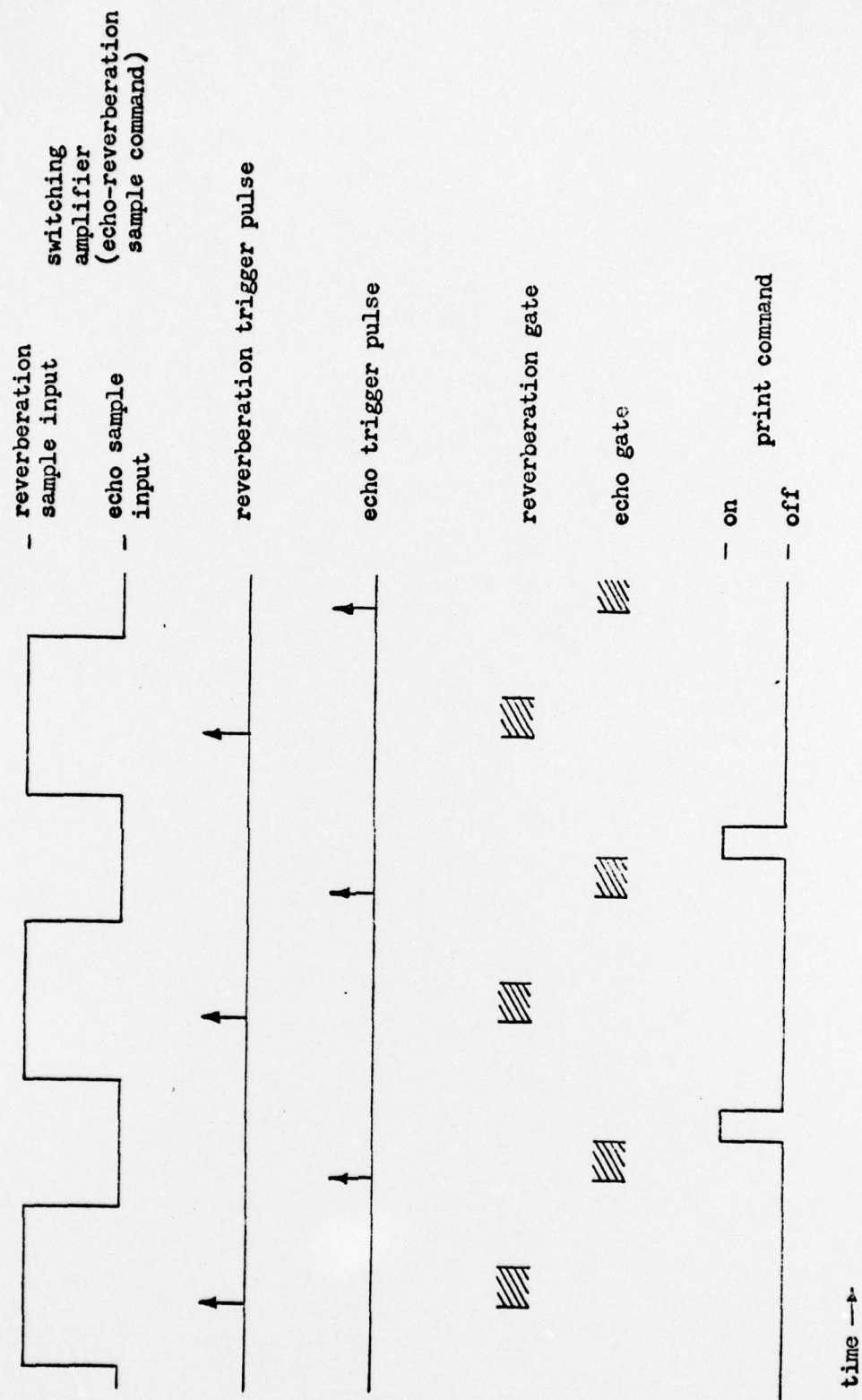


Figure 3. Timing diagram for 3D experimental setup

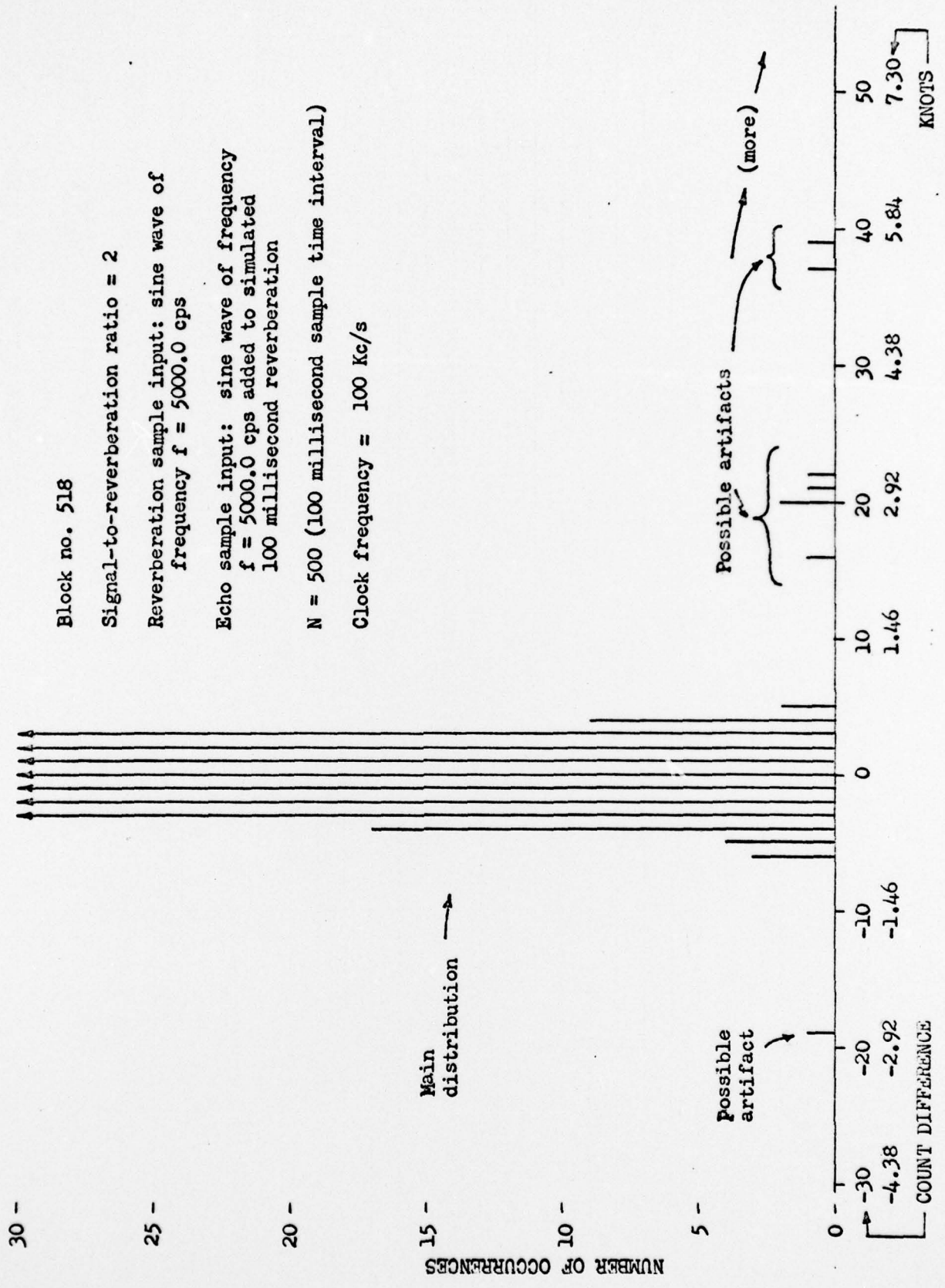


Figure 4. Typical block of data illustrating measurement artifacts

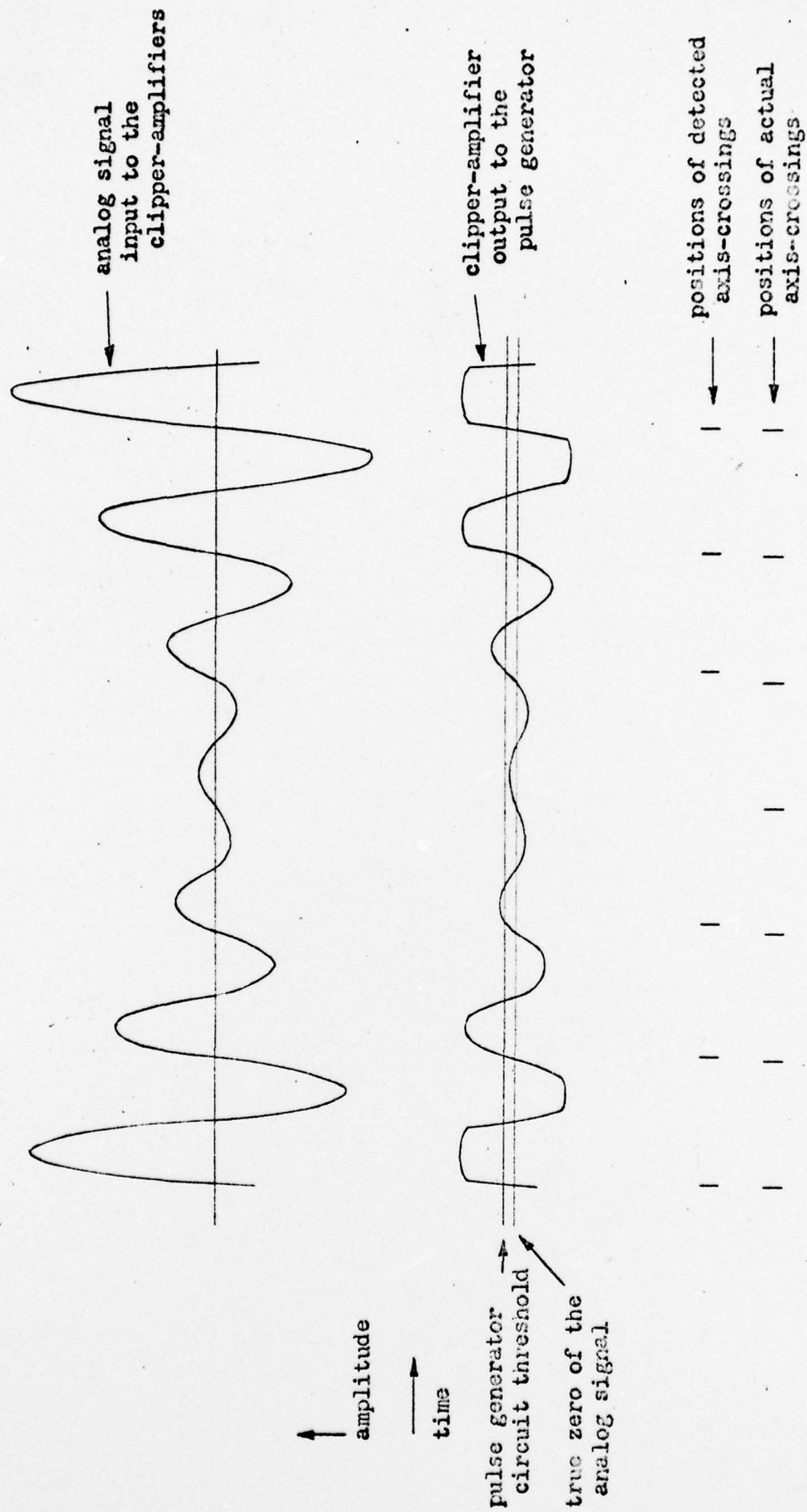


Figure 5. Effect of the pulse generator circuit threshold on axis-crossing detector performance.

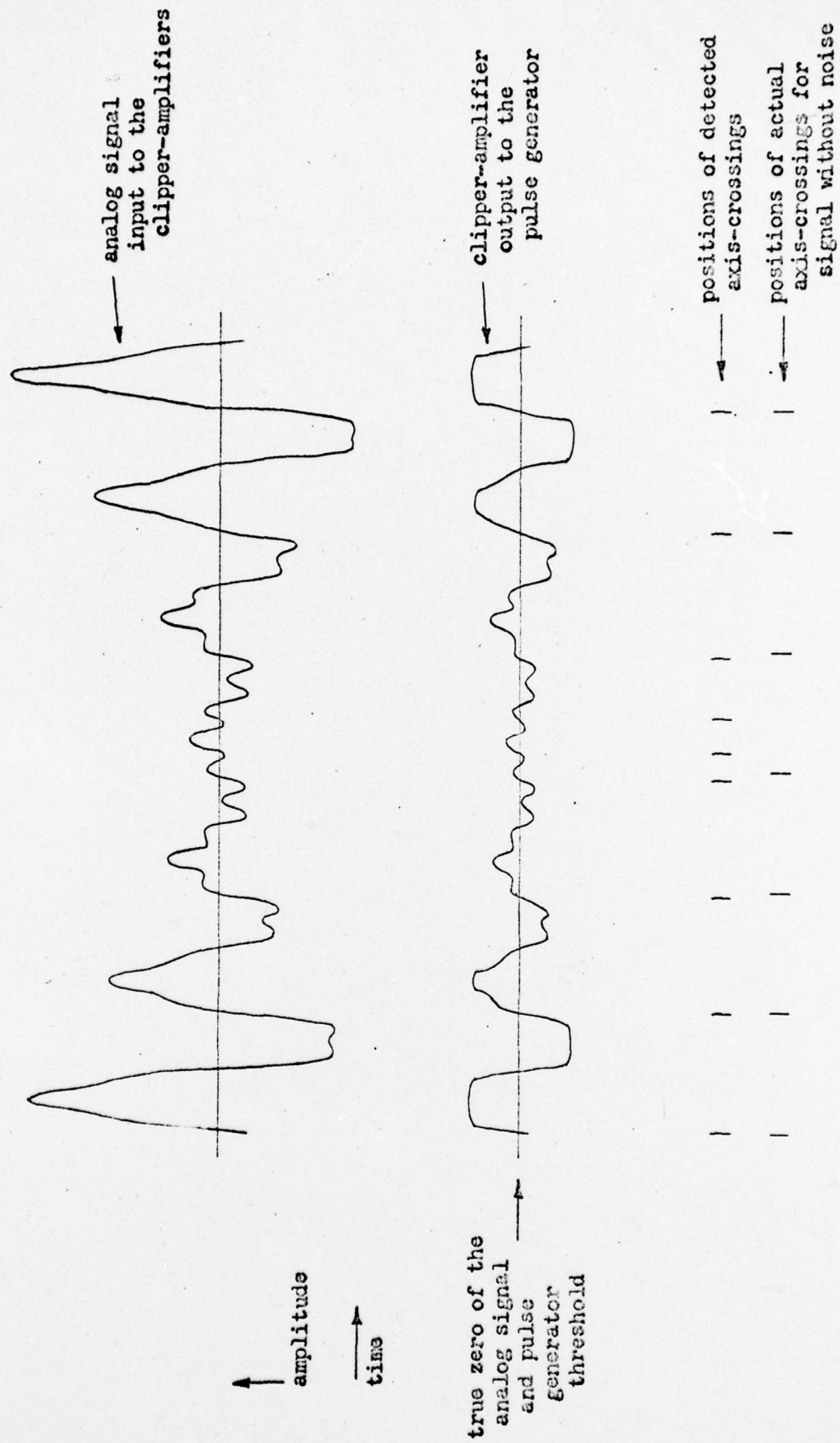


Figure 6. Effect of high frequency noise on axis-crossing detector performance.

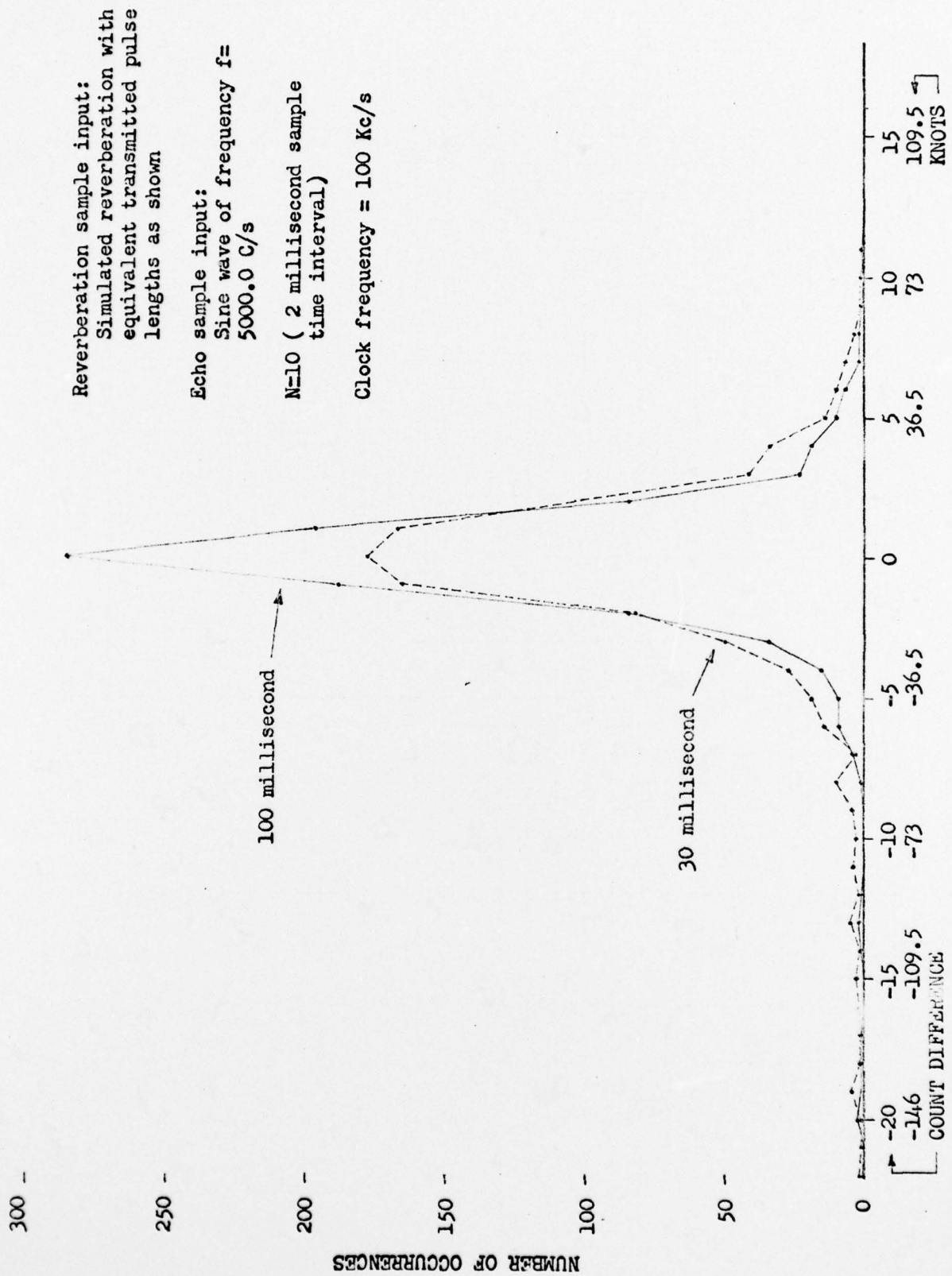


Figure 7. Variability of 3D measurements as a function of reverberation bandwidth.

Reverberation sample input: Simulated reverberation with an equivalent transmitted pulse length of 100 milliseconds

Echo sample input: Sine wave of frequency $f = 5000.0$ C/s

$N = 10, 50, \text{ and } 500$

Clock frequency = 100 Kc/s

- Notes: (1) One count difference is equivalent to approximately 7.3 knots doppler relative to a transmitted center frequency of 5 Kc/s
(2) The data for $N = 50$ and $N = 500$ are normalized with respect to the data for $N = 10$. See Table 1 for the normalization procedure

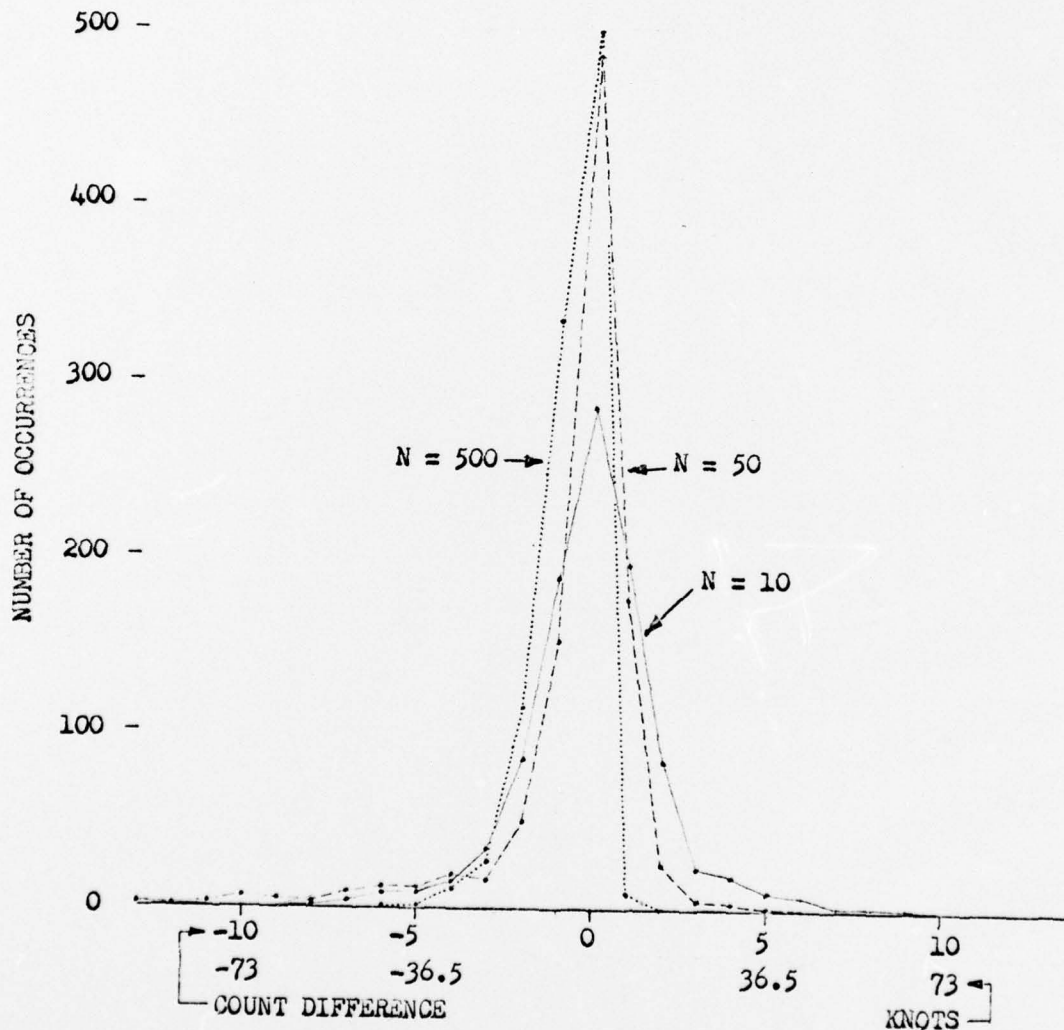


Figure 8. Variability of 3D measurements as a function of N .

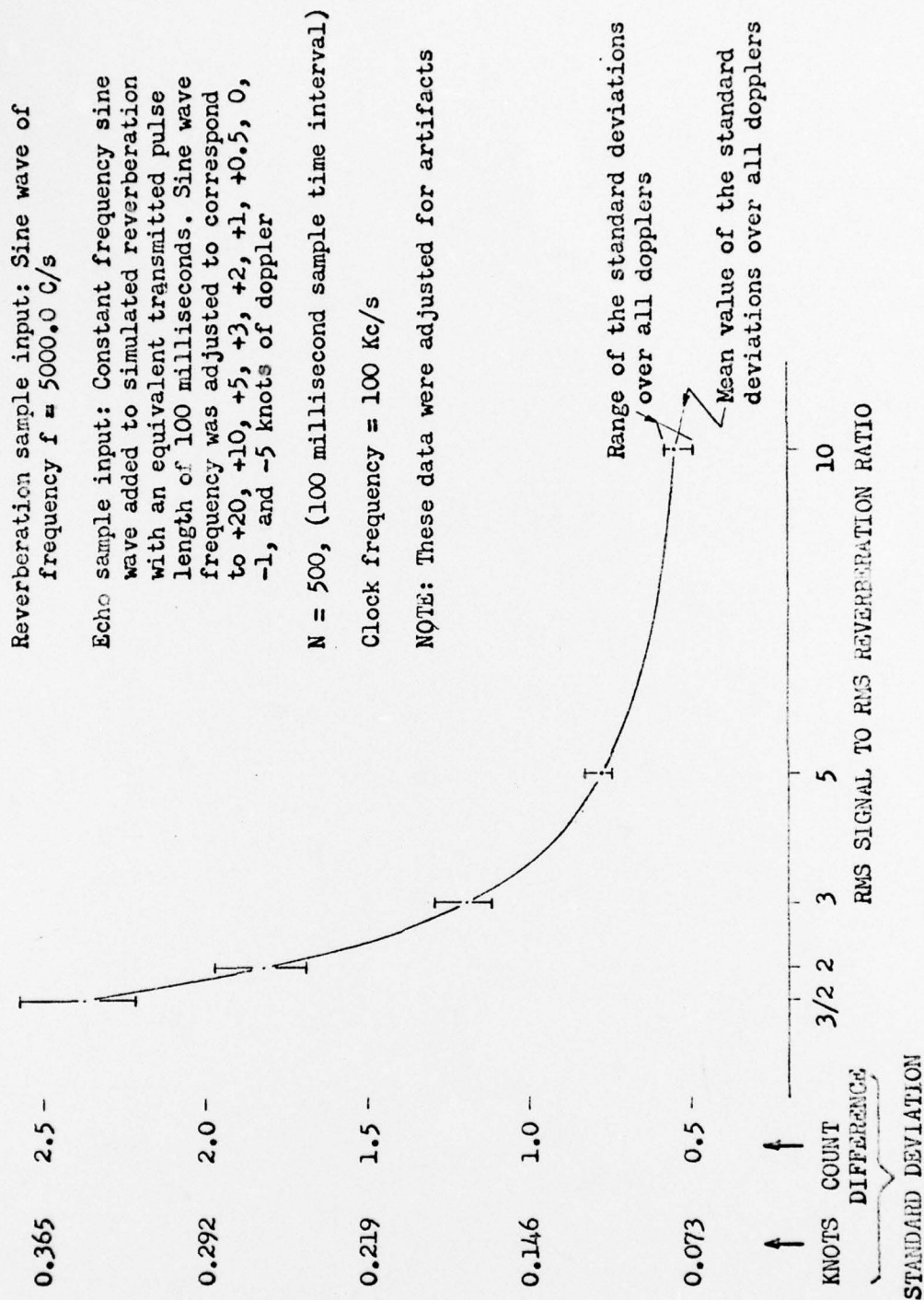


Figure 9. Standard deviation of 3D measurements as a function of the rms signal to rms reverberation ratio: 100 millisecond reverberation.

NOTE: The parameters for these data are given in Figure 9

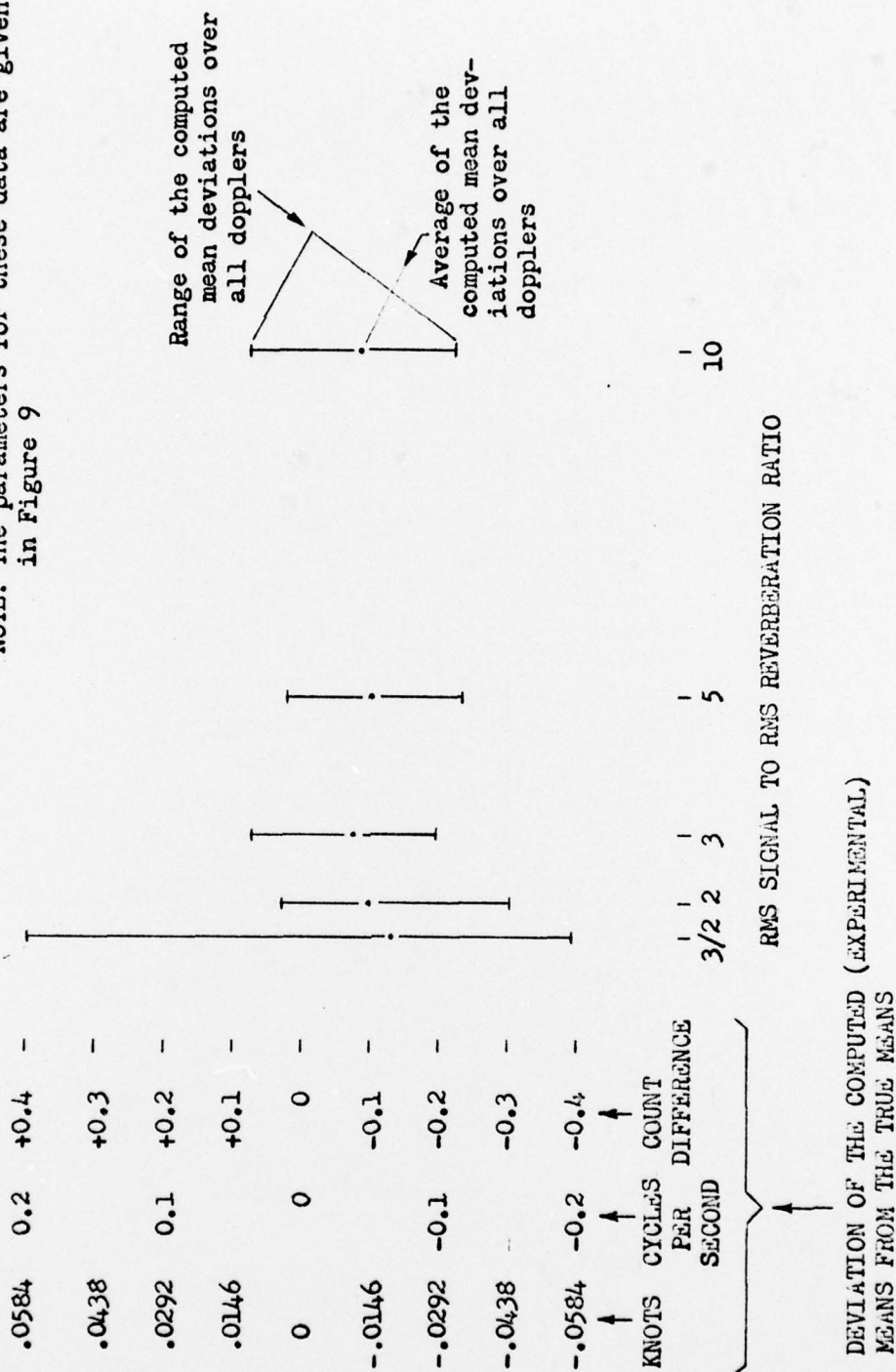
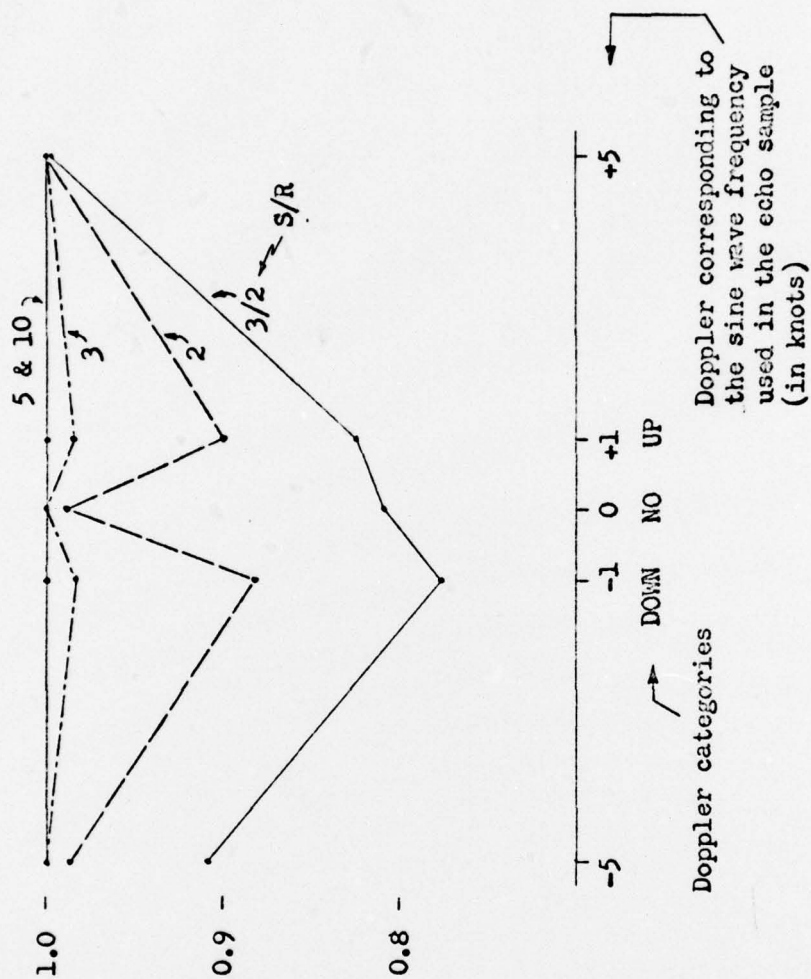


Figure 10. Deviation of the computed (experimental) means from the true means as a function of rms signal to rms reverberation ratio: 100 millisecond reverberation.

PROPORTION OF MEASUREMENTS RESULTING
IN THE CORRECT DOPPLER CATEGORY



NOTES: (1) S/R = RMS signal to RMS reverberation ratio
 (2) The parameters for these data are given in Figure 9 with the exception that adjustment was not made for artifacts

Figure 11. Doppler indicator performance as a function of echo doppler and rms signal to rms reverberation ratio: 100 millisecond reverberation.

Reverberation sample input: Sine wave of frequency $f = 5000$ C/s

Echo sample input: Constant frequency sine wave added to simulated reverberation with an equivalent transmitted pulse length of 30 milliseconds. Sine wave frequency was adjusted to correspond to +20, +10, +5, +3, +2, +1, +0.5, 0, -1, and -5 knots of doppler

$N = 50$, (10 millisecond sample time interval)

Clock frequency = 1.0 Mc/s

Notes: (1) Artifacts were not present in these data
(2) The dashed line shows data for 100 millisecond reverberation instead of 30 millisecond reverberation. In this case a zero doppler sine wave was used for the echo sample. All other parameters are the same as above

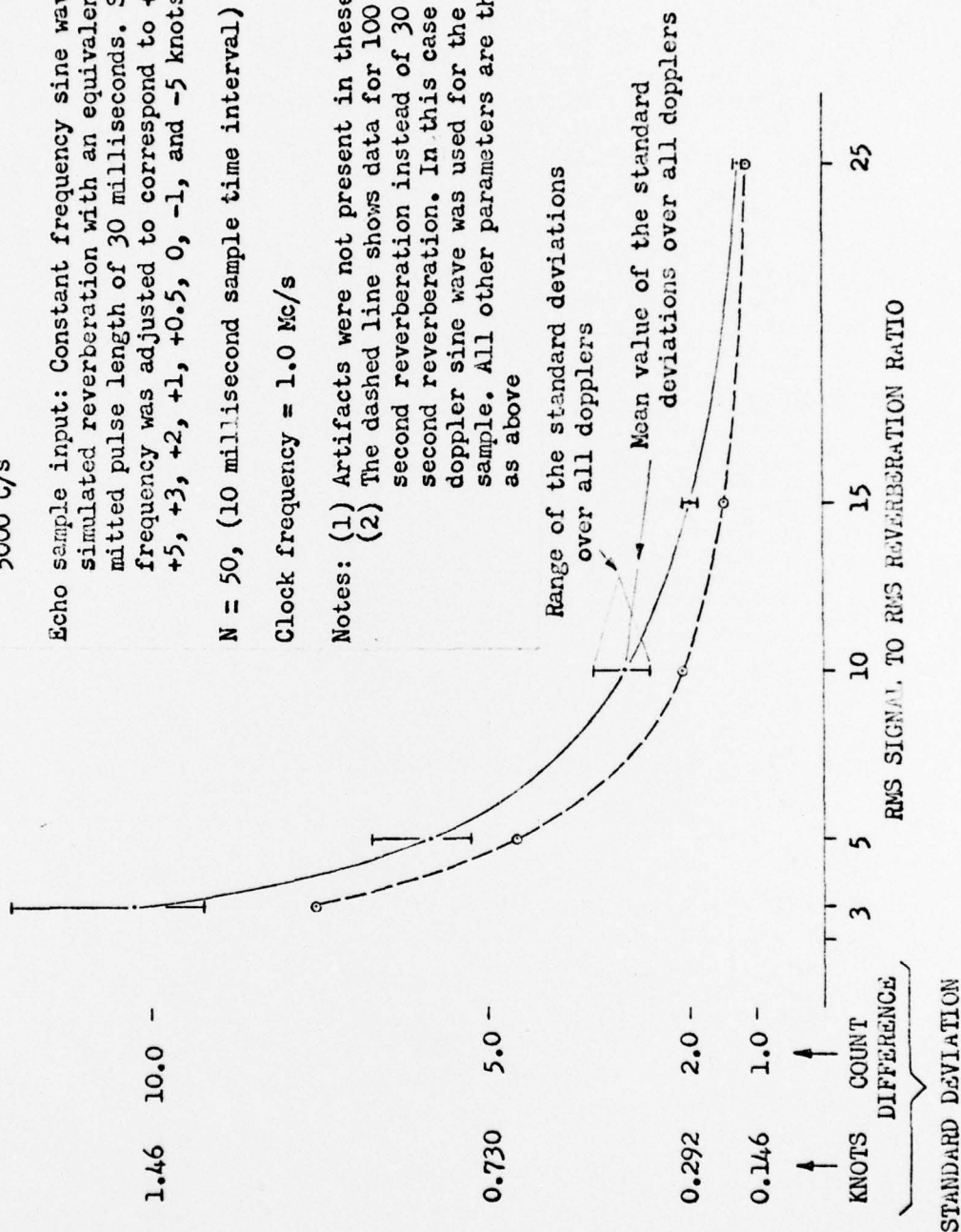


Figure 12. Standard deviation of 3D measurements as a function of rms signal to rms reverberation ratio: 30 millisecond reverberation.

NOTE: The parameters for these data are given in Figure 12

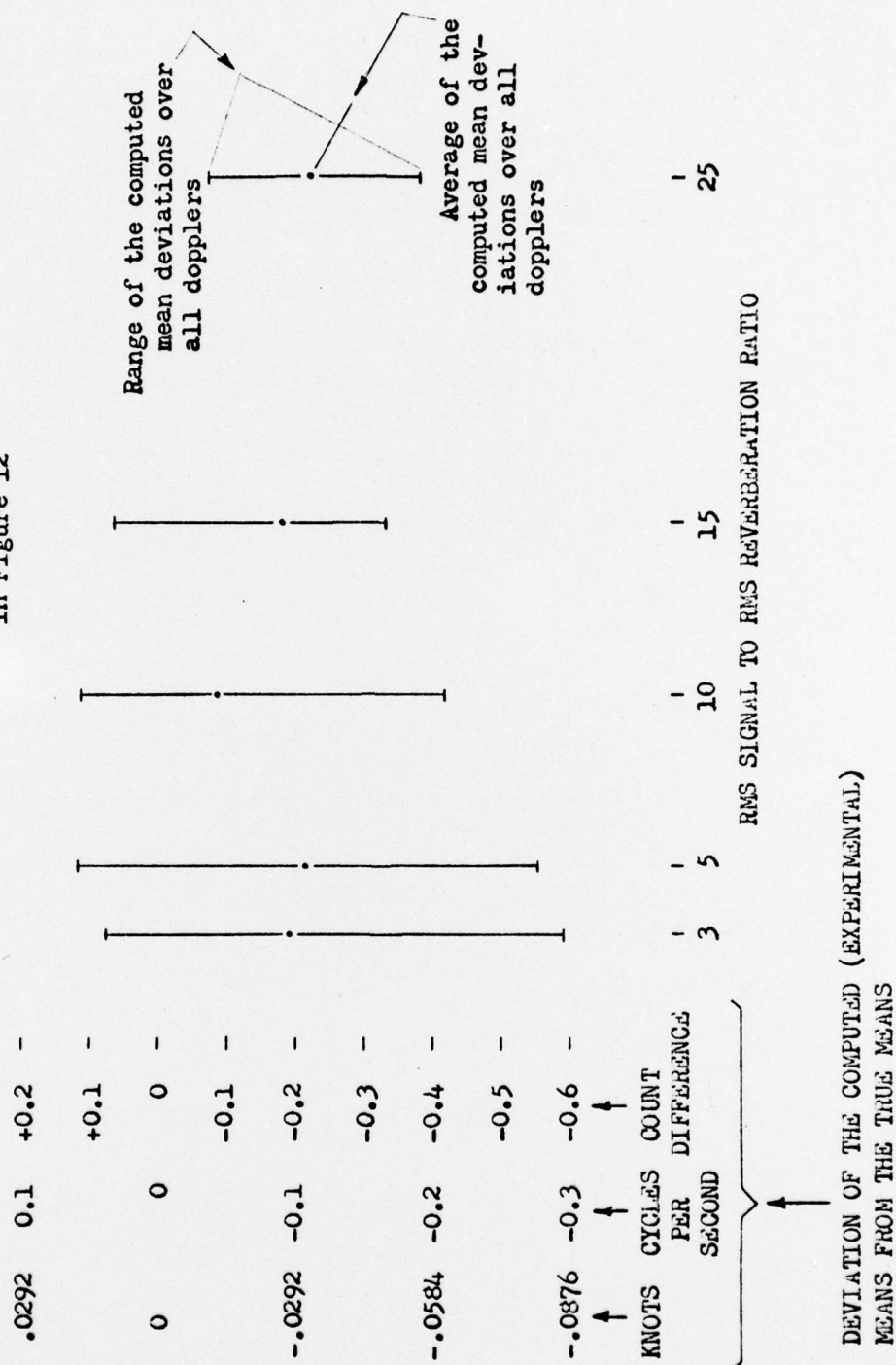
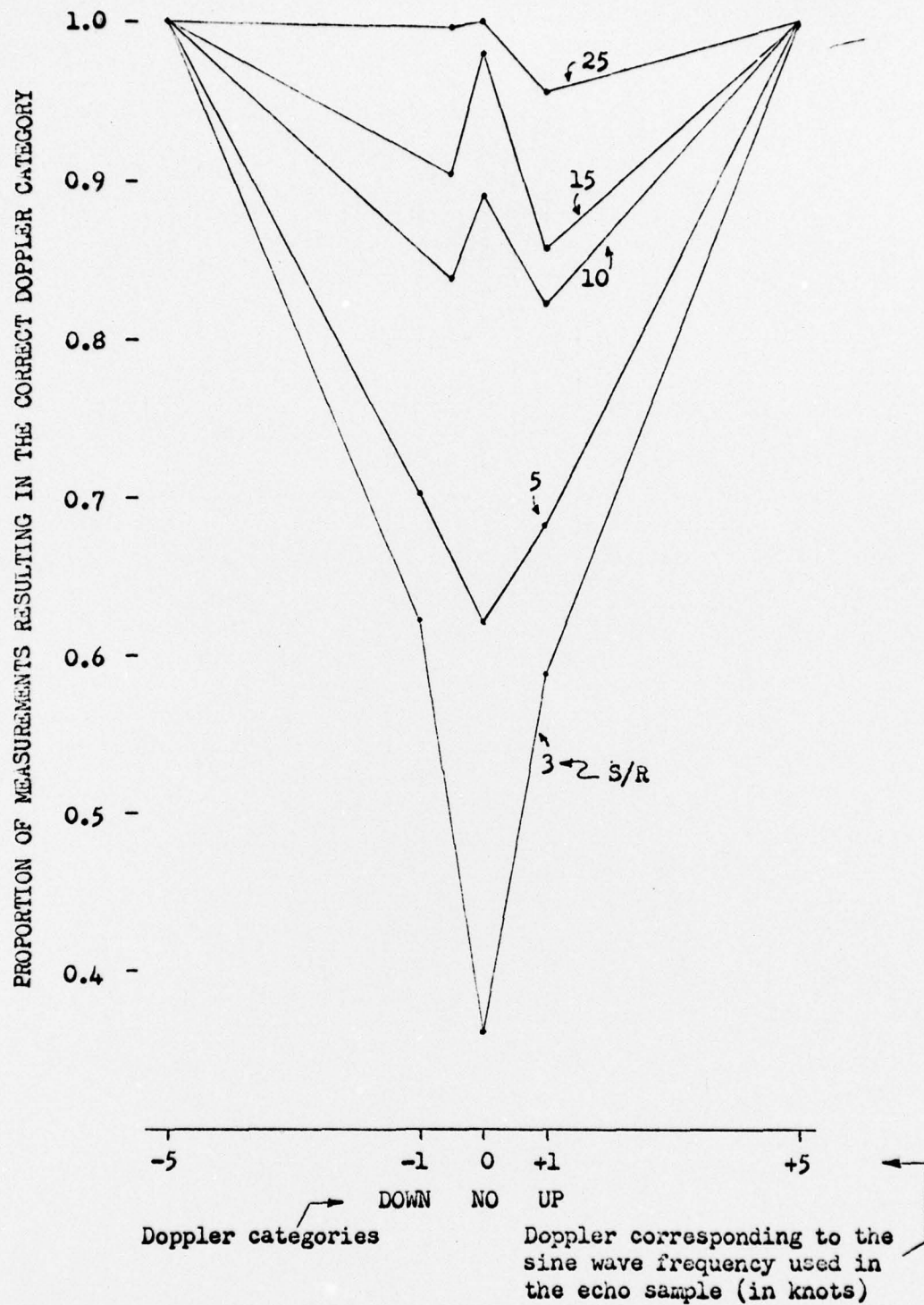


Figure 13. Deviation of the computed (experimental) means from the true means as a function of the rms signal to rms reverberation ratio: 30 millisecond reverberation.



- NOTES: (1) S/R = RMS signal to RMS reverberation ratio
 (2) The parameters for these data are given in Figure 12

Figure 14. Doppler indicator performance as a function of echo doppler and rms signal to rms reverberation ratio: 30 millisecond reverberation.